ARCTIC AND ANTARCTIC PRODUCTIVITY

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Abstract. The productivity of the polar regions has become increasingly important and this is reflected by the increased scientific interest in these areas. A review of some of the literature has been made and estimates of primary productivity for both the Arctic and Antarctic are included. A critique of some of the methods employed and the interpretation of results is also included.

INTRODUCTION

Any discussion of productivity in the Arctic and Antarctic must include some consideration of the similarities and differences of the two regions.

The similarities are quite obvious and just the mention of "Arctic" or "Antarctic" is sufficient to bring a mental picture of ice, snow and harsh environmental conditions to most people. Almost everyone knows that the higher latitudes receive much less direct solar radiation than do the temperate and tropical regions. Solar energy is of course the ultimate energy source for all living systems and this difference in available energy is evident in the fewer species and lower growth rates in polar regions. The Arctic and Antarctic regions are similar in general physical and atmospheric conditions but as Dunbar (1968) points out, they differ widely in almost every other aspect. The North Pole is a large ocean surrounded on almost all sides by land, while the South Pole is a large island continent surrounded by oceanic waters.

The Arctic land mass and the Arctic ocean is very low in productivity generally while the land mass of the Antarctic is almost entirely covered by ice all year. The marine environment surrounding the Antarctic has been described by some as the most productive area of the world (Saijo and Kawashima 1964; Walsh 1969).

DISCUSSION

Primary production is the most important form of production since it is upon primary production that all other forms are based. There are three basic factors upon which primary production depends. These are a. a minimum temperature requirement, b. sufficient light for photosynthesis and c. a supply of inorganic nutrients (and water for terrestial primary production). Any one of these factors if in short supply can be a limiting factor. In marine

production the first two factors are not normally limiting anywhere in the world, including the polar regions. Bunt (1968) for example has found several species of diatoms which grow in the Antarctic sea-ice. These are obligately psychrophilic and have an extreme capacity for shade adaptation. Even in the extremely low temperatures encountered in the Arctic and Antarctic where sea water may approach $-2^{o}C$, photosynthesis can still be carried out. There is, however, some evidence that extremely low temperature does slow down the rate of primary production (Saijo and Kawashima 1964). Saijo and Kawashima found high concentrations of nutrients in their sample area and incident radiation was also adequate so they concluded that low temperatures must account for the rather low primary productivity values of from 0.01 to 0.15 g C/m^2/day, which they found in Antarctic waters.

Walsh (1969) points out that estimated annual productivity in the Antarctic ranges from 3.6 to 331.2 g C/m^2/yr. This is "net" phytoplankton production. He also points out that for subtropical areas the yearly "net" production ranges from 5 to 912 g C/m^2/yr. These estimates were made by several different people working at different times in different areas and using different methods. Walsh states that many of the measurements were obtained with the ^{14}C method which gives values somewhere between net and gross photosynthesis. Other estimates were based on data obtained by the light and dark bottle O_2 method which yields an estimate of gross primary production. Nutrient depletion was also used as a method of estimating primary production by one worker. Walsh states the view that Antarctic waters were highly productive was based on estimates of instantaneous standing crop rather than on an annual basis. Also some workers only considered the top 50 metres of the water column while it is known that the euphotic zone extends to at least 100 metres in subtropical areas. Walsh summarizes his paper by stating, "It is suggested that contrary to earlier estimates, the Antarctic ecosystem may be equivalently or less productive than other areas of the world ocean in assimilation and storage of energy."

There would seem to be a considerable degree of subjectivity in interpreting the results of primary productivity estimates. For example, Gulland (1970) states, "The primary production in the Antarctic expressed as carbon fixation per unit area is fairly high compared with most parts of the open ocean, though less than in some of the most productive areas (e.g. some sub-tropical upwelling areas). Figures quoted for the average production per year have ranged from 40 to 100 g C/m^2."

Frey and Stahl (1958) in their study of two Canadian Arctic lakes compare the productivity they measured to that of the Sargasso Sea. They state, "It would also have been much less than the net annual phytoplankton production of the Sargasso Sea (50 g C/m^2/yr as listed by Riley 1957), a region notoriously low in production." This statement is included to illustrate something of the degree of subjectivity encountered in some of the work on primary productivity. Gulland (1970) feels that a net annual pro-

ductivity of 40 to 100 g C/m^2 as representative of "a region notoriously low in production". One would certainly expect somewhat more agreement as to just what does constitute "high" or "low" primary productivity.

A comparison of the various estimates of primary productivity is also made very difficult by the fact that different methods are often used and the results obtained are expressed in different ways. For example, in g C/m^2 or g C/m^3. The time period may be expressed in terms of hours, days or years. Most primary productivity studies in polar regions are carried out over extremely short periods of time. The common procedure is then to use the data obtained from this short period and extrapolate over the mean growing period to get an annual figure. Estimating yearly production from brief studies in this manner could be hazardous and the results may be subject to large errors.

Apparently even less work on primary productivity has been done in the Arctic than the Antarctic. Peterson (1964) gives a figure of 36 g C/m^2/yr for a region near Disko Island, West Greenland. This was the result of a two year study in which the ^{14}C technique was used. Petersen also includes some estimates from Steeman Nielsen (1958 b) for South Greenland where estimates varied from 29 to 98 g C/m^2/yr and for several areas in Denmark waters which yielded values ranging from 6 to 1175 g C/m^2/yr. These values are as high as those for the Antarctic and would seem to support the findings of Walsh (1969). Dunbar (1968) offers an explanation for the rather high productivity in the Antarctic and some areas of the Arctic. Nutrients are brought to the surface by the upwelling of deep water in the area of the Antarctic convergence. This increase in nutrients promotes the growth of phytoplankton and results in the higher productivity observed. The Arctic convergence is much more diffuse but in the area from Newfoundland to the Barents Sea a broad zone in which there is a great deal of mixing of the Atlantic and Arctic waters. In the rest of the Arctic the water shows extreme stability and although nutrients are present in adequate quantities, they do not reach the euphotic zone and may be accumulating in the deeper layers. Dunbar defines this zone of mixing as the "marine subarctic" although it extends well north of the Arctic circle in several places. The area studied by Petersen (1964) lies well within this "marine subarctic".

Even less work has been done on the productivity of fresh water in the polar regions. In the Antarctic there are very few lakes. Goldman et al. (1967, 1969) carried out studies on four such lakes. Their work was concerned mainly with the daily changes in productivity in two shallow lakes and their figures are given in mg C/m^3/hr. No attempt was made to estimate the annual production. The other two lakes studied were Lake Vanda and Lake Bonney, two Antarctic desert lakes. Primary productivity in Lake Vanda was found to be 14 mg C/m^2/day in terms of surface units and 0.24 mg C/m^3/day in terms of volume. The euphotic zone was considered to extend to 60 m. Lake Bonney

yielded a photosynthetic rate of 31 mg C/m^2/day to a depth of 10 m. A maximum rate of 8 mg C/m^3/day was found in the warmer zone in 5 m beneath ice-water interface. Both of these lakes are permanently frozen except for melting around their margins during the summer. They are among the clearest lakes known.

In the Canadian Arctic, Frey and Stahl (1958) obtained values of 90 mg C/m^3/day and 50 mg C/m^2/day for a very shallow lake (maximum depth 1m) on Southampton Island and values of 1.5 mg C/m^3/day and 9 mg C/m^2/day for a deeper lake (maximum depth 10 m) in the same area. Their study was carried out over approximately two weeks (using the ^{14}C method) and no attempt was made to estimate annual production. Frey and Stahl compare their values to those obtained by Comita and Edmondson (1953) for Imikpuk Lake near Pt. Barrow, Alaska. Production estimates here had a mean value of 58 mg C/m^3/day and 120 mg C/m^2/day and were based on the oxygen procedure. Frey and Stahl calculated that if this mean rate of production was carried out over the ice-free period of 65 days, total annual production would be 7.8 gC. They also assumed that no production would occur under the ice. However, productin does occur under the ice in the presence of light and Rodhe (1955) has found evidence that algal growth may even occur in the absence of light.

Productivity of the land environment of polar regions is extremely low. In the Antarctic the land mass is covered with ice which precludes almost all terrestrial primary productivity. In the Arctic, the land is free of ice for at least part of the year and so terrestial primary production can occur. From my own observations, the vegetation of the high Arctic islands is very sparse. In addition to the low temperatures affecting growth, water also seems to be a limiting factor since growth generally occurs in low areas where water is available throughout the growing season. In fairly wet areas the growth of grasses, sedges and mosses becomes relatively lush. The soils also appear to be generally very poor with very little humus material. In isolated areas where some humus has built up the growth of vegetation is considerably greater. This is probably due to the water-holding ability of humus as well as the improvement in available nutrients.

Estimates for tundra production range from 0.2 to 0.6 g/m^2/day (total dry weight) averaged over teh whole year, which is about 20% of the production for good temperate woodlands (Downes 1964). In the more extreme region of the high Arctic, production may be of the order of 0.01 g/m^2/day, total dry weight based on the whole year.

SUMMARY

The Antarctic marine environment has long been considered to be a highly productive area. However, some recent work indicates that it is perhaps not as productive as was formerly thought (Walsh 1969). Polar regions have long been neglected for scien-

tific study due to the harsh climate and the expense of transporting equipment and supplies vast distances. Recently there has been a great deal of interest shown in these regions. This is due in part at least to the discovery of vast oil and gas reserves in the Arctic. The Antarctic has been the object of scientific research for a somewhat longer time and now shows some promise of providing food for an ever-increasing world population.

A number of estimates for primary production in different areas have been summarized and attention drawn to the difficulties of comparing the various results. It would appear that the polar regions will become increasingly important as the search for new energy and food supplies intensifies. Evidence of increased scientific interest in our own Arctic is found in the International Biological Programme projects now underway.

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